

AN EXPERIMENTAL INVESTIGATION OF PRESSURE ATTENUATION IN TYPICAL
MISSILE PLUMBING SYSTEMS SUBJECTED TO SHOCK WAVE INPUTS--
EFFECT OF VARIATION OF RECEIVER VOLUME

A THESIS

Presented to

The Faculty of the Graduate Division

by

Lester R. Smith

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Aeronautical Engineering

Georgia Institute of Technology

September, 1958

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EFFECT OF VARIATION OF RECEIVER VOLUME

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ACKNOWLEDGMENTS

The author expresses his appreciation to Doctor Arnold L. Ducoffe for suggesting the subject and giving invaluable assistance through all phases of work. Gratitude is also extended to Doctor Robin B. Gray and Doctor Thomas W. Jackson for their critical review of the topic and to Messrs. J. Van Tassel, G. W. Stone, and R. T. Walters for their assistance in making the apparatus and in conducting the tests.

Sincere appreciation is extended to the Sandia Corporation for the financial and material aid which made this work possible.

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LIST OF SYMBOLS

C	empirical constant
cps	cycles per second
cu. in.	cubic inches
D	test line inside diameter, inches
K	empirical constant
L	tube length, inches
$P_{I_{max}}$	maximum input static pressure, psig
$P_{R_{max}}$	maximum response static pressure, psig
psig	pounds per square inch gage pressure
R_D	reduction fitting diameter ratio, insert I.D./D
V	receiver volume, cubic inches

SUMMARY

An experimental investigation was conducted to determine the effect of the receiver volume on the attenuation of a shock wave propagated down a system of tubing, fittings and volumes representative of the type used in pressure-sensing systems of missiles.

A shock tube whose downstream end was open to the ambient air was used to generate shock waves. A sample of the shock wave was taken by a test system of small diameter tubing, diameter reduction fittings and various volume receivers. Pressure-sensing transducers, connected to an oscillograph through an amplifier, recorded the transient pressures of the shock wave as it passed the entrance of the pickup tube and as it reached the receiver volume. Three receiver volumes (10.55, 53.9, and 109.5 cubic inches) were tested with two tube diameters (0.242 and 0.370 inches), two reduction fittings (100 and 50 per cent of line diameter), two line lengths (1 and 15 feet), and seven shock tube pressures (50, 100, 200, 350, 500, 700, and 1000 psig).

It was concluded that the maximum response pressure, $P_{R_{max}}$, could be related to the maximum input pressure, $P_{I_{max}}$, by:

$$P_{R_{max}} = CV^{-0.64} P_{I_{max}}$$

where V is receiver volume in cubic inches and C is a function of line length, line diameter, and reduction fitting diameter.

CHAPTER I

INTRODUCTION

The pressure-sensing system familiar in the airplane as the altimeter is still used in many missiles and rockets. This baro-sensing system may be used to actuate different components of the rocket or to arm or detonate the missile, or both. An anti-missile missile with a proximity fuse might explode near the pressure-detonated missile causing a shock wave which is picked up by the barometric pressure-sensing system of the missile. If the explosion were large enough and near enough to the missile, the shock wave might be strong enough to damage the aneroid system and prevent the missile from detonating at its pre-determined altitude or the missile might explode immediately, even though above the desired altitude.

Some work has already been done on the study of the pressure attenuation and pressure lag of various components in baro-sensing systems. Most of this investigation has been confined to the low pressure range (one-half to 3 atmospheres) and little has been done at the higher pressures. DeJarnette (Reference 1) investigated the effect of tube length and diameter on the attenuation of shock waves with pressures of 40-900 psig. Kilburg (Reference 2) extended this to include the effect of diameter reduction fittings. The purpose of this experimental research is to extend the work done by DeJarnette and Kilburg and investigate the effect of variation of receiver volume (V) on the attenuation of shock

waves in typical missile plumbing system. The investigation is conducted over the same pressure range, approximately 40-900 psig. Variations in tube length (L), tube inside diameter (D), and reduction fitting diameter ratio (R_D) are also investigated.

CHAPTER II

APPARATUS

The test equipment and instrumentation consisted of a compressed air supply, control panel and pressure gages, shock tube, nozzle with pressure "O" ring and diaphragm, firing unit, pickup test tube and straight-through fittings modified for diameter reduction inserts, receiver volume, pressure transducers, and amplifying and recording equipment.

Compressed air supply.--An Ingersoll-Rand four-stage air compressor (model GC-50-BW) with a capacity of twenty cubic feet per hour, and a pressure limit of 3000 pounds per square inch, supplied compressed air to a storage tank. The compressor was driven by a Waukesha Model 6-BZ six-cylinder gasoline engine.

Control panel and pressure gages.--A schematic of the control panel and gages is shown in Fig. 1. Compressed air was fed from the compressor accumulator to the control panel via a vapor separator through 1/4 in. extra heavy¹ copper tubing. A 3000 psig gage on the control panel gave the compressor tank pressure. A sensitive 0-1000 psig gage, with a readability of 2 psig, was used to obtain shock tube pressures, calibrate the pressure transducers and detect air leaks in the test and shock tube systems. This sensitive gage was protected from damage of shock wave

¹See Lionel S. Marks, Mechanical Engineers' Handbook, Third Edition, 1931, p. 1028, for the dimensions of extra heavy copper tubing.

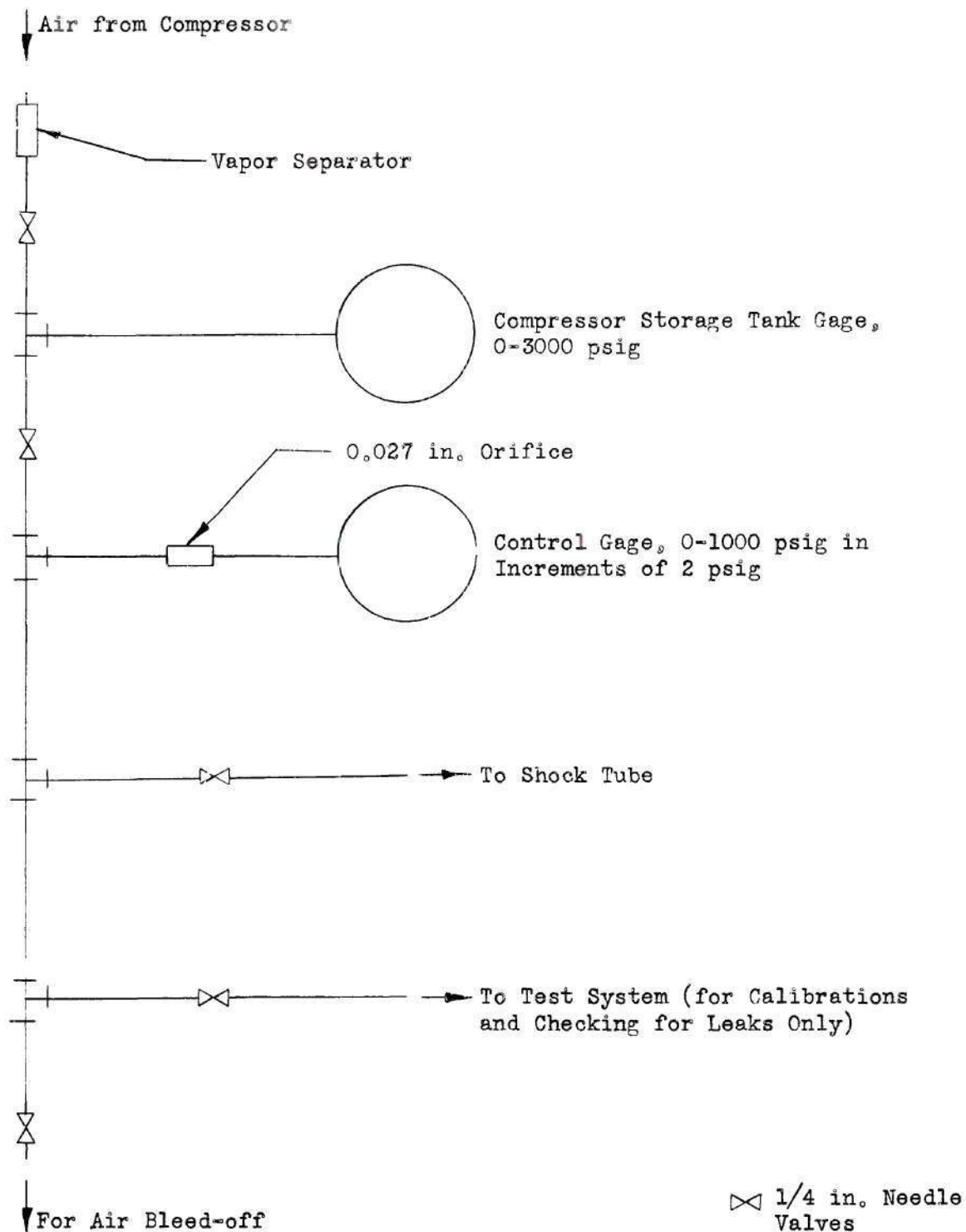


Fig. 1. Control Panel

inputs during premature diaphragm failures by a 0.027 in. orifice. Air lines to the shock tube and to the test system were controlled from the panel. A bleed-off line, used to bleed air from any part of the system, was also connected to the control panel. All control valves were 1/4 in. needle valves; all air lines were 1/4 in. extra-heavy copper tubing; and all connections were 45 degrees flare tube fittings.

Shock tube.--The shock tube was a 7.625 foot piece of cylindrical steel pipe. The outside diameter was 4-1/2 in., and the inside diameter was 3-1/2 in. which necked down to 2 in. at the downstream end, giving an inside volume of 840 cu. in. The upstream end was sealed by a blank flange which had a fitting for copper tubing leading to the control panel. The downstream end was sealed by Mylar Polyester Film diaphragms. The shock tube was mounted on a reinforced wooden table as shown in Fig. 2. The table was fastened to a concrete pad by two ell brackets which were bolted to tamp-ins located in the pad. Each downstream leg of the table was joined by a 1/2 x 10 in. bolt axially through a recoil spring to the vertical member of an ell bracket as shown in Fig. 3. The upstream end of the table was fastened by guy wires.

Nozzle.--A 2 in. diameter nozzle was attached to the downstream end of the shock tube with Mylar diaphragms between the shock tube and nozzle as shown in Fig. 4. The thickness of the diaphragms, as shown in Table 1, was sufficient to maintain the desired shock tube pressure yet thin enough to fail rapidly and completely when desired. A 2-1/2 x 2-3/4 x 1/8 in. rubber "O" ring recessed 1/16 in. into the downstream end of the shock tube insured an airtight seal. The "O" ring had to be replaced after every 10-15 runs because of nicks and abrasions in the rubber which allowed the diaphragm to slip out of its housing and blow out the end of the shock tube.

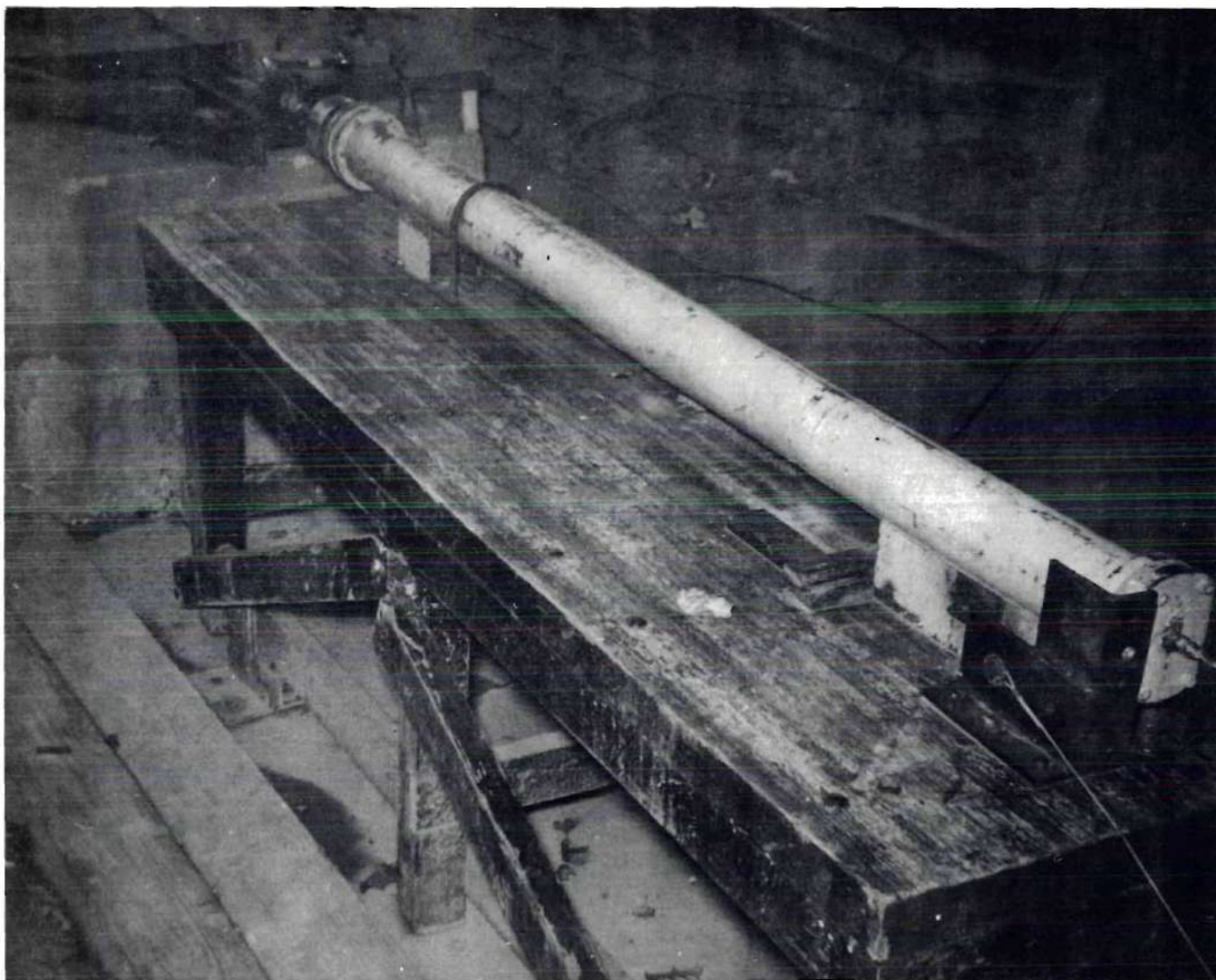


Figure 2. Shock Tube and Table.

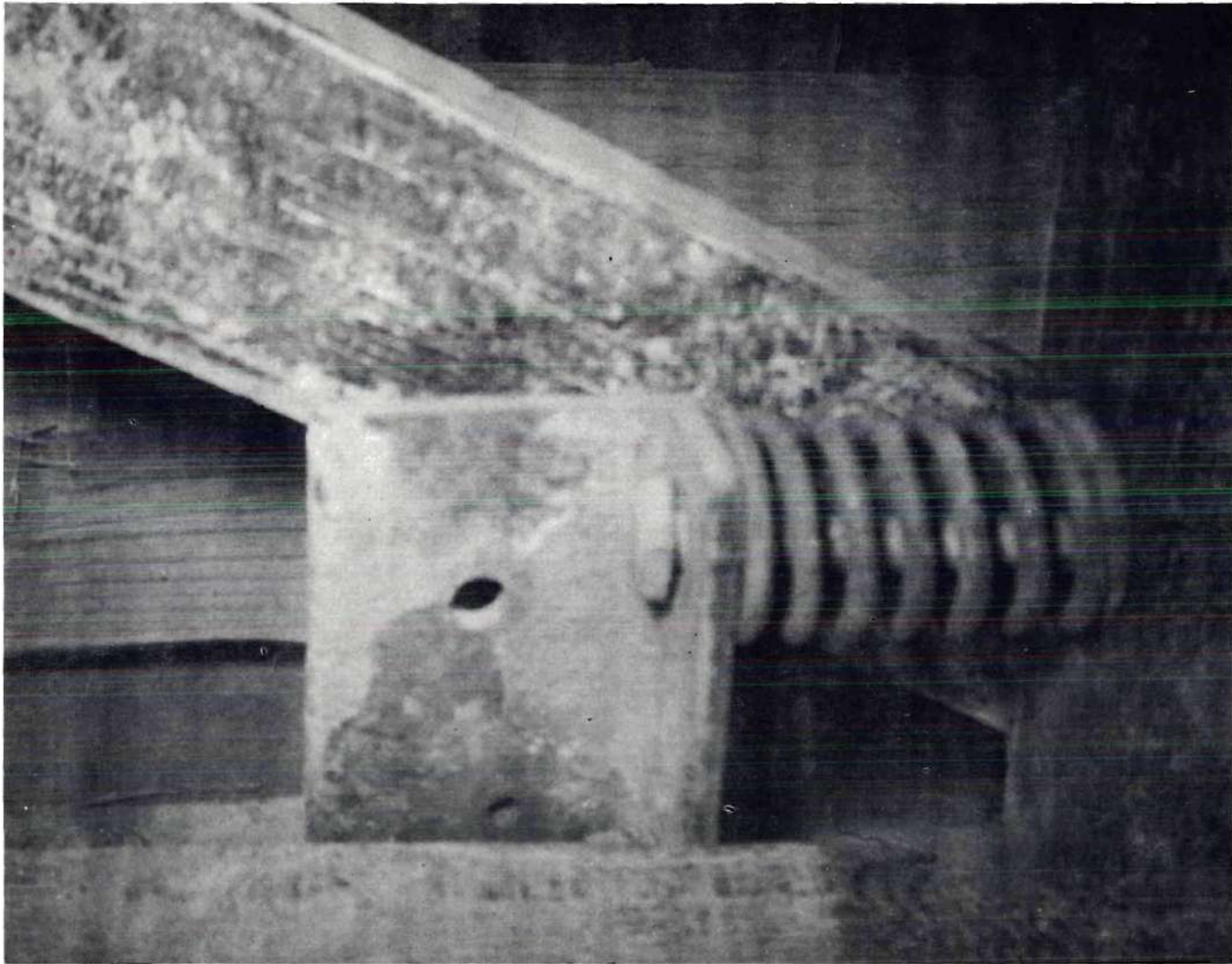


Figure 3. Recoil Spring and Ell Bracket.

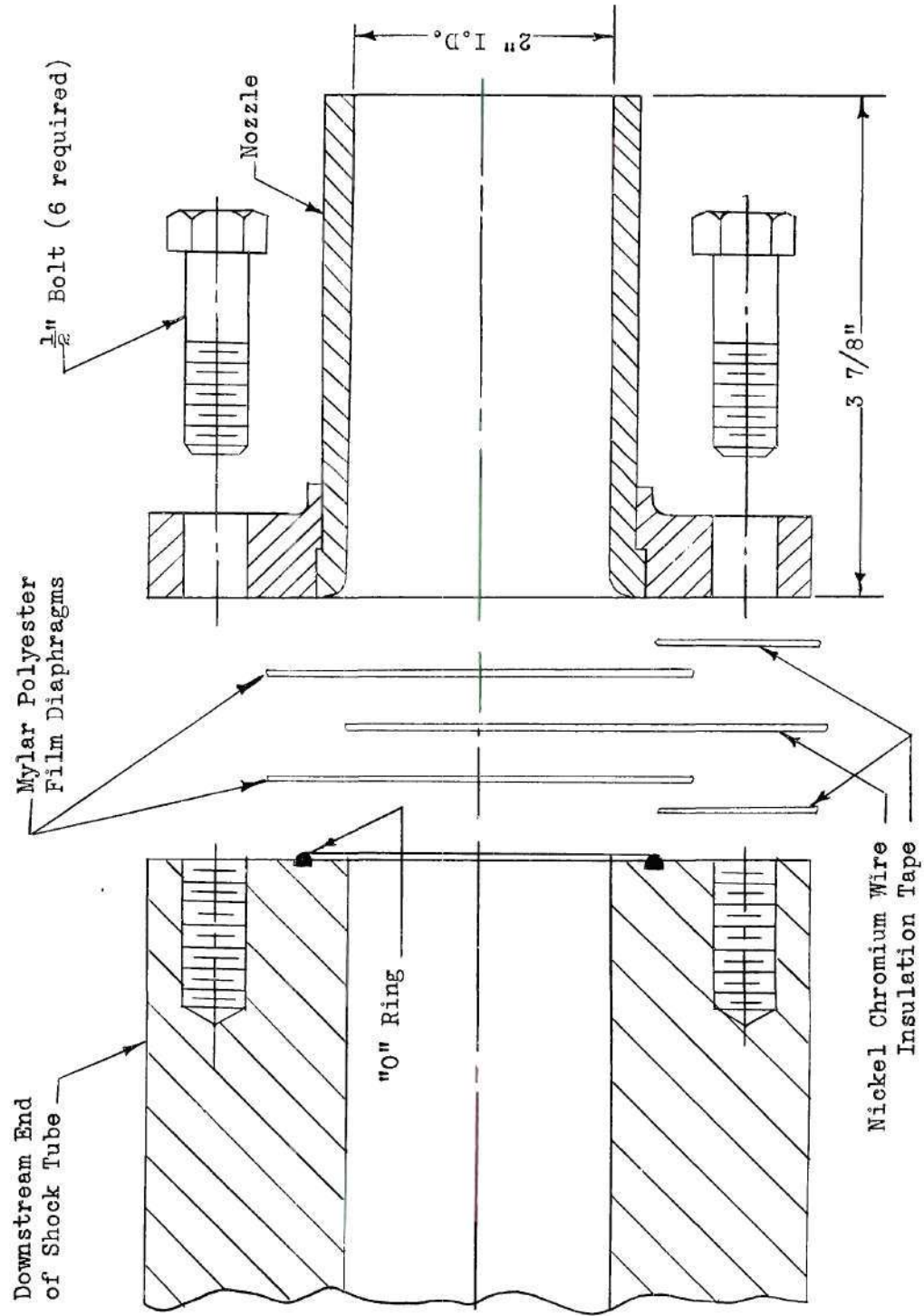


Fig. 4 Detail of Nozzle

Table 1. Diaphragm Thickness

<u>Shock Tube Pressure (psig)</u>	<u>Number of Films x Thickness of Films (mils)</u>
50	3 x 1
100	2 x 3
200	2 x 5
350	3 x 5
500	4 x 5 + 1 x 1.5
700	6 x 5
1000	6 x 7.5

Firing unit.--The firing unit, as shown in Fig. 5, consisted of a transformer, a toggle switch, an ohmmeter and a heating wire. The heating wire was nickel chromium high resistance wire. The wire was passed between the layers of film in the diaphragm and out between the flanges of the nozzle and shock tube to the leads from the 16 volt transformer. The wire was insulated from the metal flanges by strips of insulating tape. The first runs were conducted with 0.012 in. wire, which broke frequently during firing and often cut through the insulating tape, shorting the electrical circuit. Wire of 0.018-0.024 in. diameter was most satisfactory. The part that passed between the flanges was flattened to approximately 0.008 in. which almost totally eliminated the short circuits. The ohmmeter was used to test for short circuits after bolting down the nozzle and for detecting a broken firing wire while applying pressure. The deflection of the Mylar diaphragm as pressure was applied to the shock tube would occasionally cause the wire to break.

Pickup tube, test tube and inserts.--The test system which included the pickup tube, test line, inserts, receiver volume, and pressure transducers is shown schematically in relation to the tube and nozzle in Fig. 6. The pickup tube, a 0.56 in. inside diameter tube shown in Fig. 7, was mounted on a channel beam "A" frame that was bolted with 2 x 1/4 in. bolts to the concrete pad. The pickup tube was fixed so that it was centered vertically and laterally with the shock tube nozzle. The longitudinal adjustment of the entrance of the pickup tube was maintained at 1/8 in. upstream (inside) of the exit of the shock tube nozzle by adjusting the recoil springs on the downstream legs and the guy wires on the upstream end of the table. The pickup tube was butted to a changeable fitting, which was made from a Parker straight-through con-

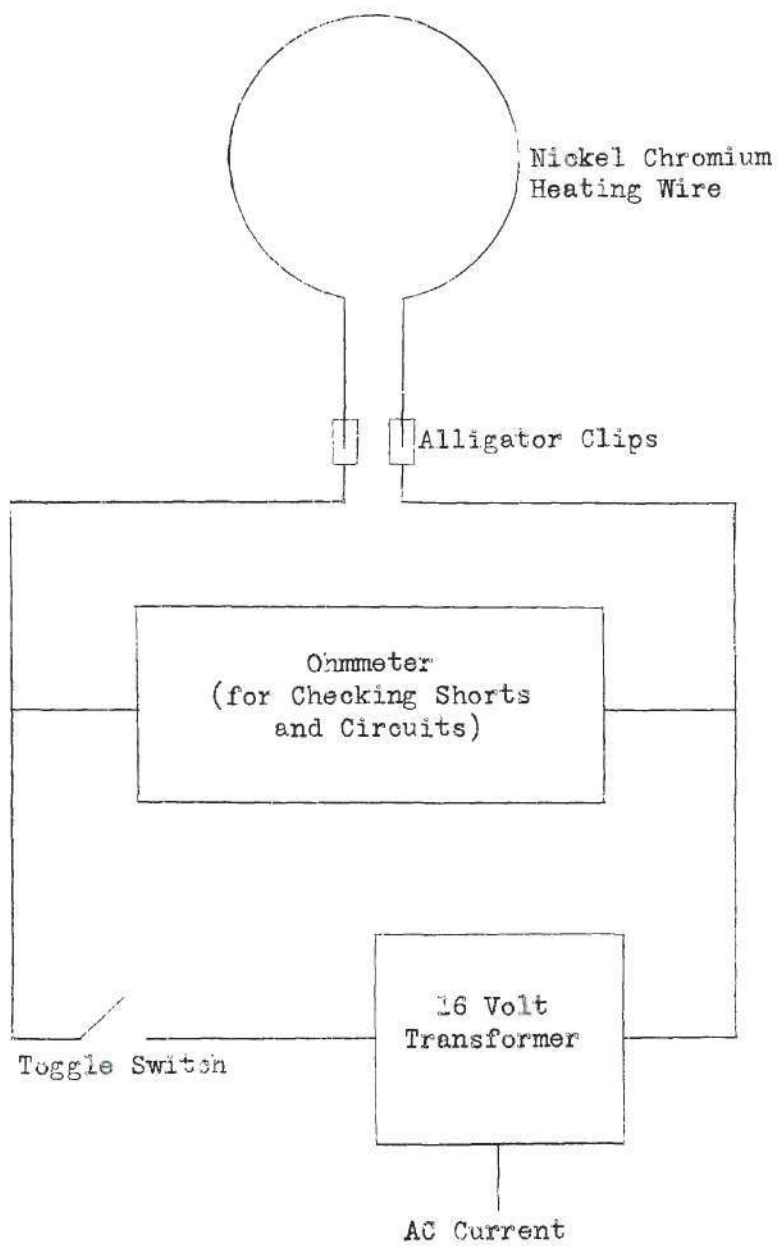


Fig. 5 Firing Unit

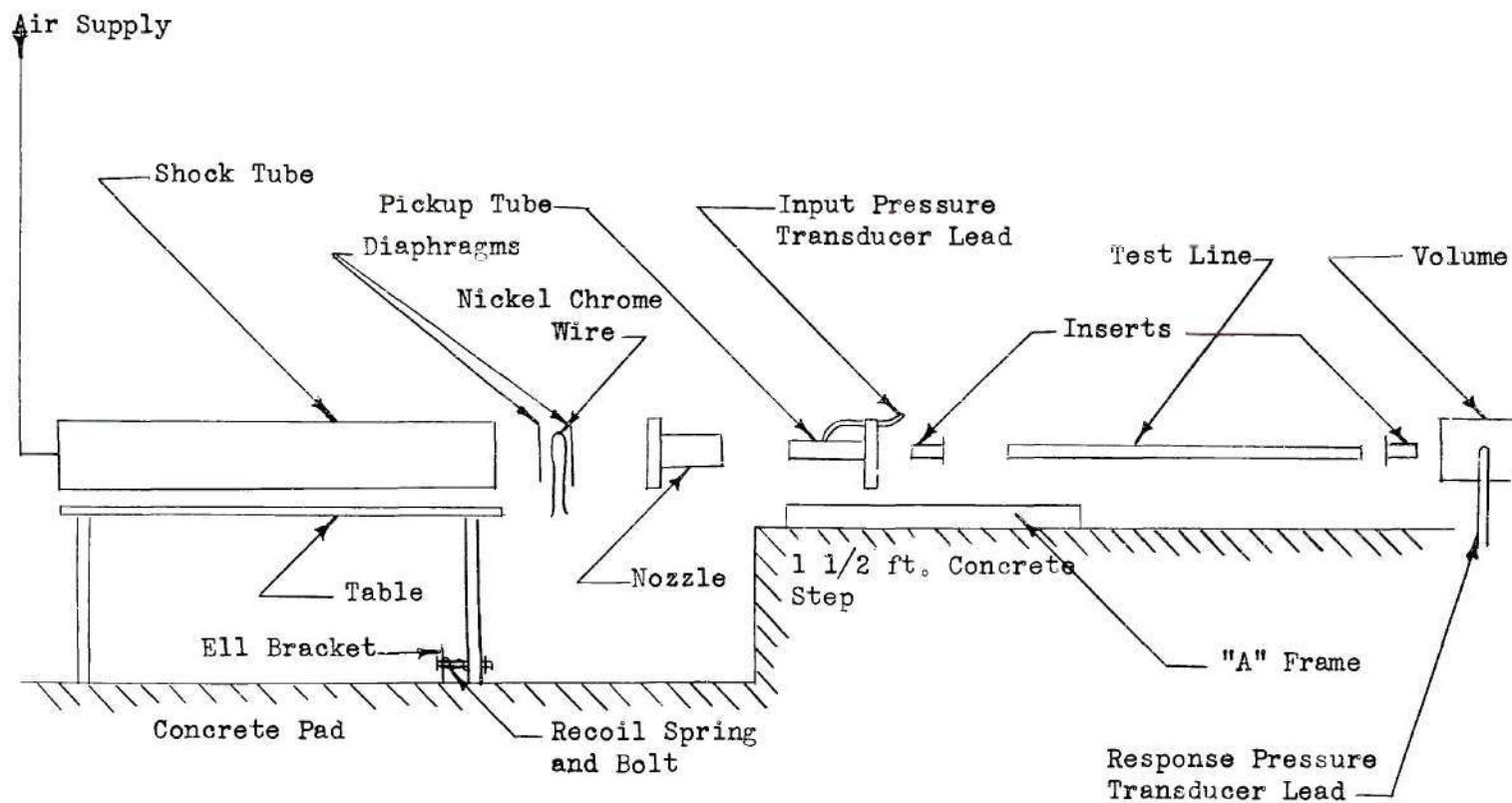


Fig. 6 Test Apparatus Schematic

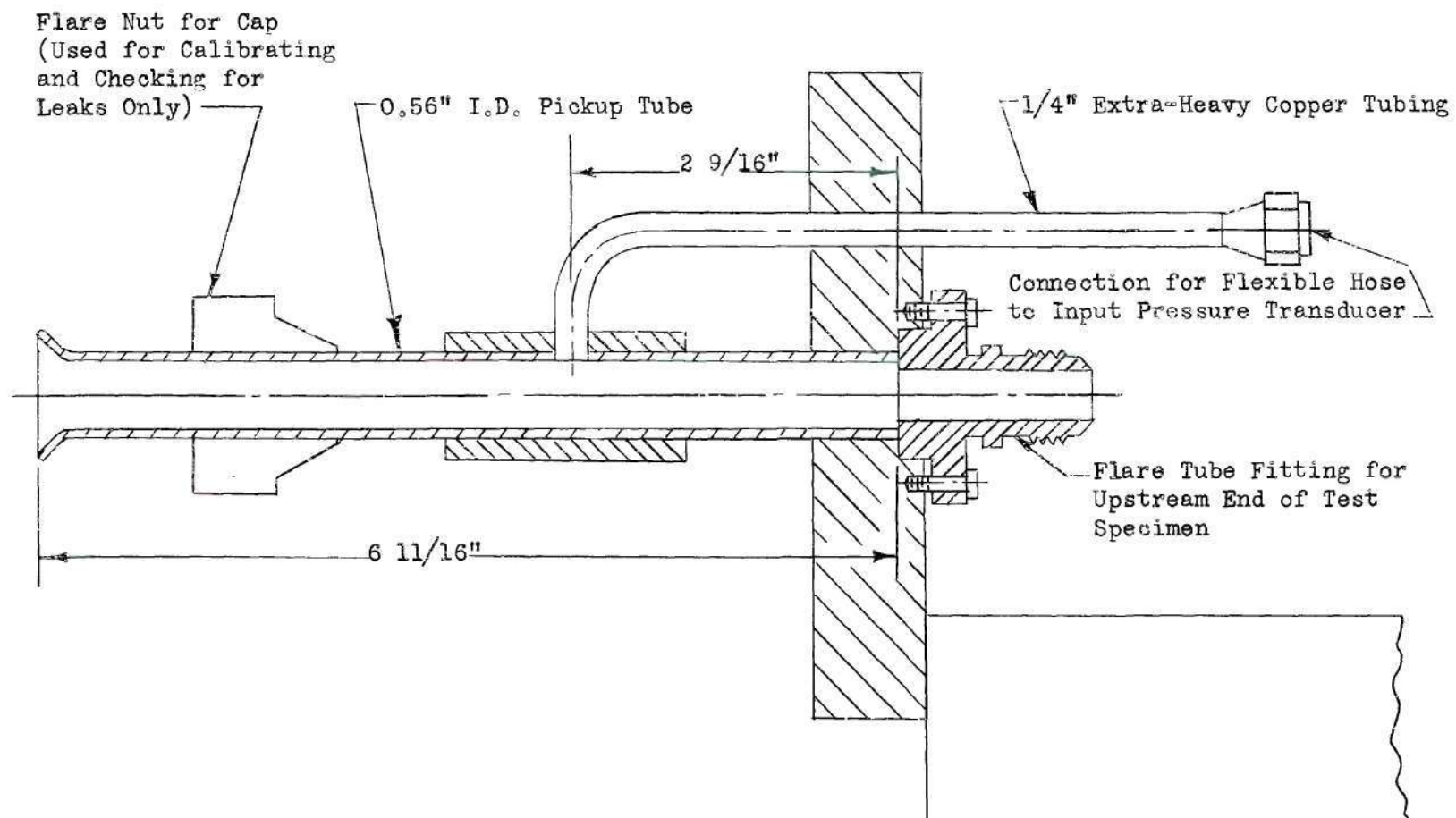


Fig. 7 Detail of Pickup Tube

nector fitting and sealed with an "O" ring. The Parker fitting had been modified to take one of two inserts as shown in Fig. 8. The insert sizes and diameter ratios are given in Table 2. The heads of the inserts were bevelled to 45 degrees to connect with the 45 degree flare of the test tubing. There were four test lines as shown in Table 2. The downstream end of the test tubing was connected to the receiver volume by means of a Parker straight-through fitting which had been modified to take the line reduction inserts as explained above.

Receiver volumes.--There were three receiver volumes tested. The smallest volume, 10.55 cu. in. volume, is shown in Fig. 9. Spot checks were made with this volume to corroborate Kilburg's data². The other two volumes, 53.9 cu. in. and 109.5 cu. in. were identical to that shown in Fig. 9 with the following exceptions: (1) the end plates were welded in position and did not require an "O" ring; (2) there were two Parker fittings in the upstream end of the volume, an HBTX-X-5 for the 0.242 in. diameter tube and an HBTX-S-8 for the 0.370 in. diameter tube. The fitting not in use was capped off.

Transducers.--Pressure-sensing transducers were connected 4-1/8 in. from the upstream end of the pickup tube to record the input pressure and to the midpoint of the length of the receiver volume, Fig. 9, to record the response pressure. The input pressure transducer was a Statham temperature compensated, Model No. PG 10TC a - 1M-350 (0-1000 psig) transducer. The response transducer was either a Statham Model PG 132-100-350, 0-100 psig transducer for the response pressures below 100 psig or a Statham, 0-1000

²Richard F. Kilburg, An Experimental Investigation of Pressure Attenuation in Typical Missile Plumbing Systems Subject to Shock Wave Inputs--Part II, Unpublished Master's Thesis, Georgia Institute of Technology, 1958, pp. 14-17.

Note: Parker Fittings HBTX-S-8 for 0.370 in.
Line I.D.

Parker Fittings HBTX-S-5 for 0.242 in.
Line I.D.

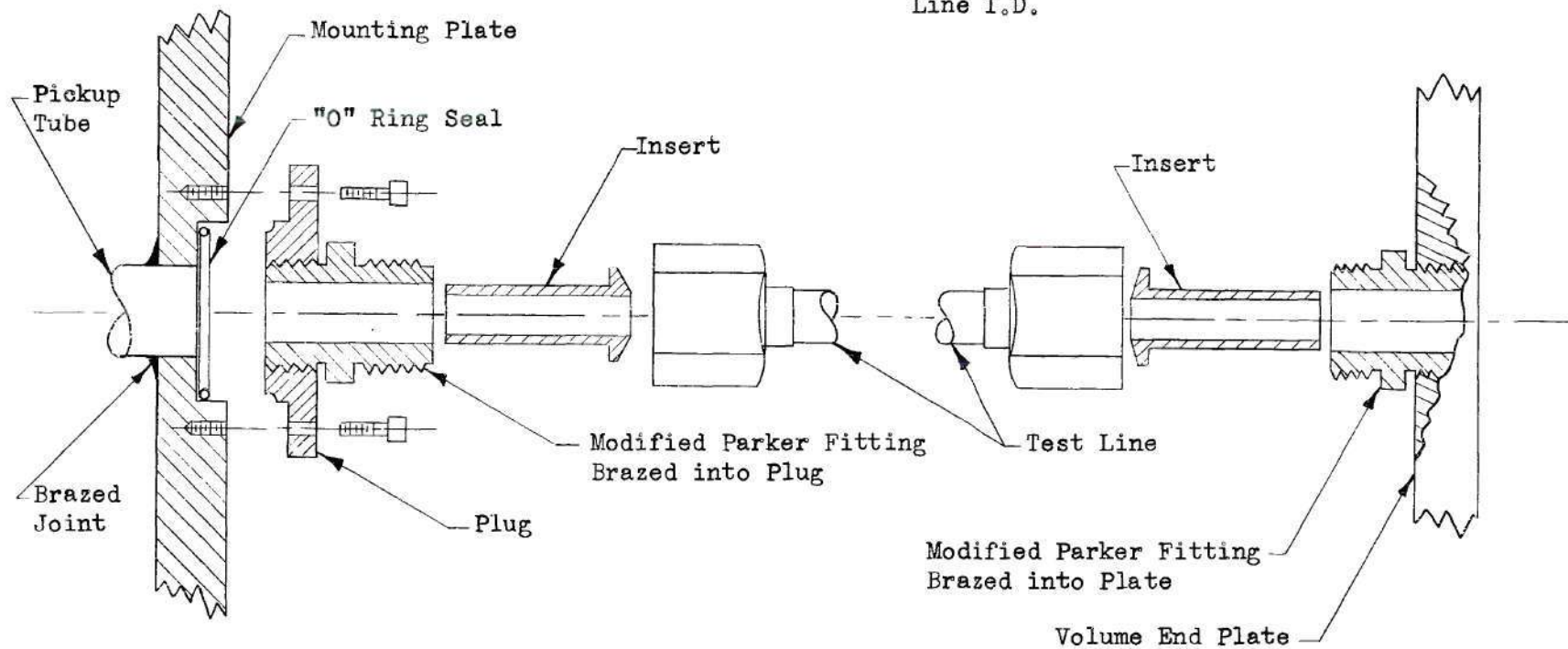


Fig. 8 Typical Fitting Installation

Table 2. Test Line and Diameter Reduction Insert Sizes

Line Size:	<u>0.242 in. I.D. x 1 ft. and 0.242 in. I.D. x 15 ft.</u>	
Insert Size:	<u>Insert I.D. (inches)</u>	<u>Diameter Ratio, R_D</u>
	0.242	1.000
	0.123	0.508
Line Size:	<u>0.370 in. I.D. x 1 ft. and 0.370 in. I.D. x 15 ft.</u>	
Insert Size:	<u>Insert I.D. (inches)</u>	<u>Diameter Ratio, R_D</u>
	0.370	1.000
	0.185	0.500

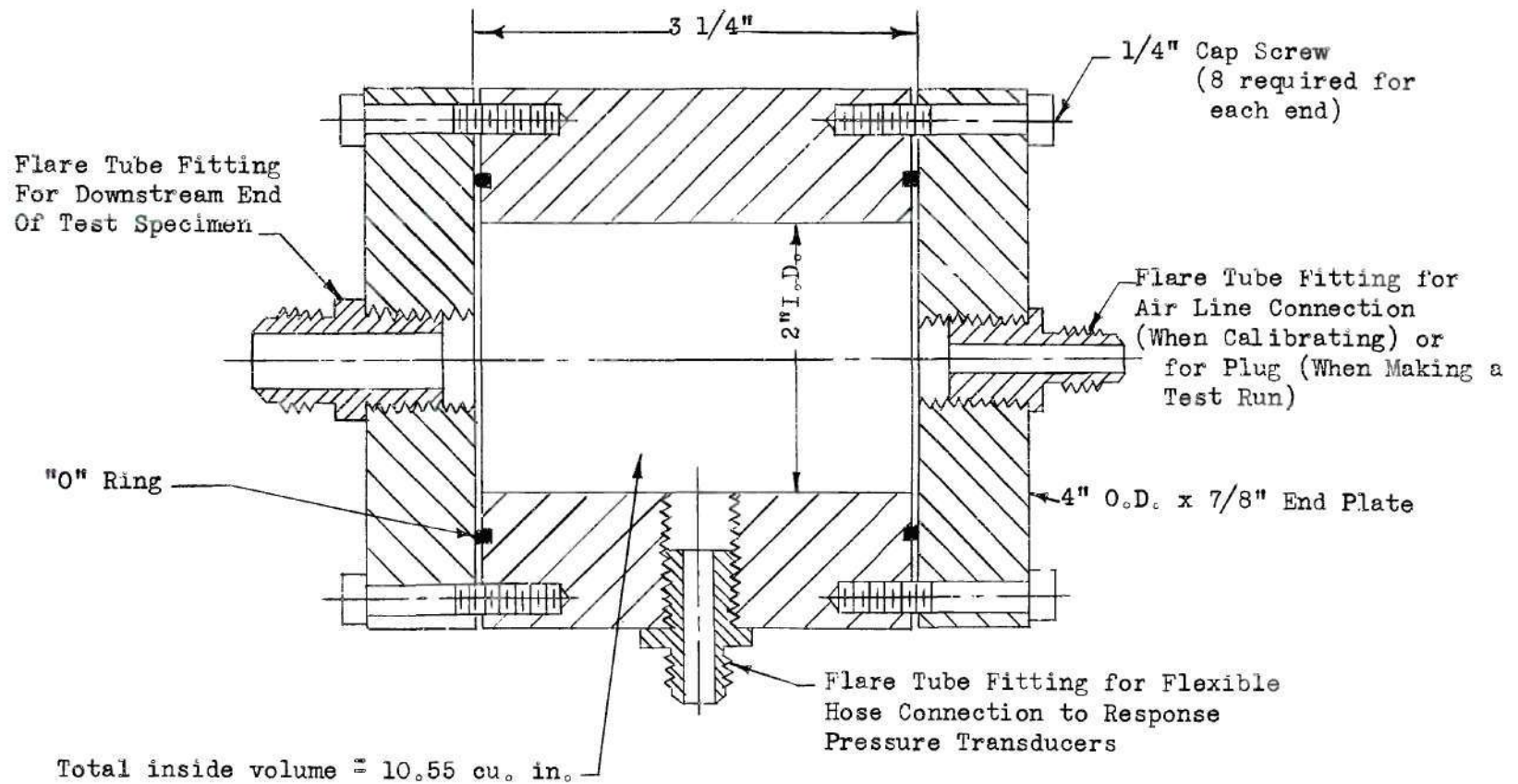


Fig. 9 Detail of Volume

psig transducer for response pressures above 100 psig. The transducers were connected to the pickup tube and volume by 15 in. lengths of flexible pressure hoses. The 0-100 psig transducer, in addition, had a 1/4 in. Hancock high pressure (0-2200 psig) Model 95CS straight-flow gate valve in line between the transducer and flexible hose so that it could be isolated from the system during tests for leaks and calibration of the input transducer. In order to minimize the effect of vibrations: 1) the transducers were rigidly mounted on base boards which were heavily weighted, and 2) the axes of the transducers were placed 90 degrees to the axis of the test system so that any motion imparted to the transducers due to the passage of the shock wave would be normal to the axes of the transducers.

Instrumentation.--The transducer outputs were linearly amplified by a Heiland (Minneapolis Honeywell) 119 amplifier system. The amplified signals were recorded with a Honeywell Model 906, direct reading, Visicorder Oscillograph. Model V1500D fluid damped galvanometers gave the recording system a 0-900 cps flat frequency response. The six inch wide Visicorder paper No. A-301151 was run at 5 in. per second. A timing trace was produced with a Hewlett-Packard Model 211A square wave generator. This instrumentation circuit is shown in Fig. 10.

After check runs with the smallest volume and 25 per cent of the runs with the two larger volumes had been completed, it was necessary to replace the Honeywell instrumentation because of a previous commitment for this equipment for another research project. The replacement instrumentation, shown in Fig. 11, consisted of a Consolidated Electrodynamics Corporation 4-channel amplifier, system D, and recording oscillograph. C. E. C. Type 7-223 fluid damped galvanometers gave the recording system a flat frequency range of 0-500 cycles per second. Eastman Linagraph 1127 paper

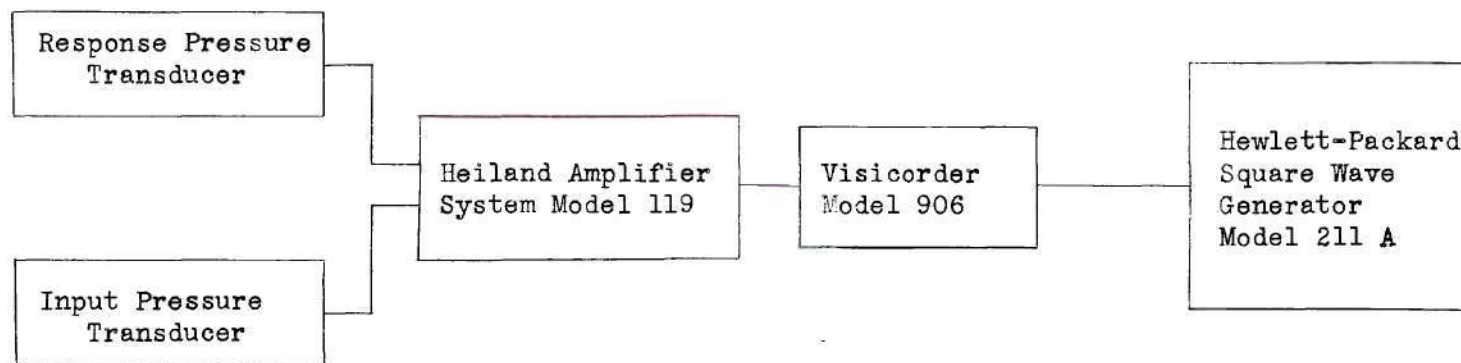


Fig. 10 Visicorder Instrumentation Circuit

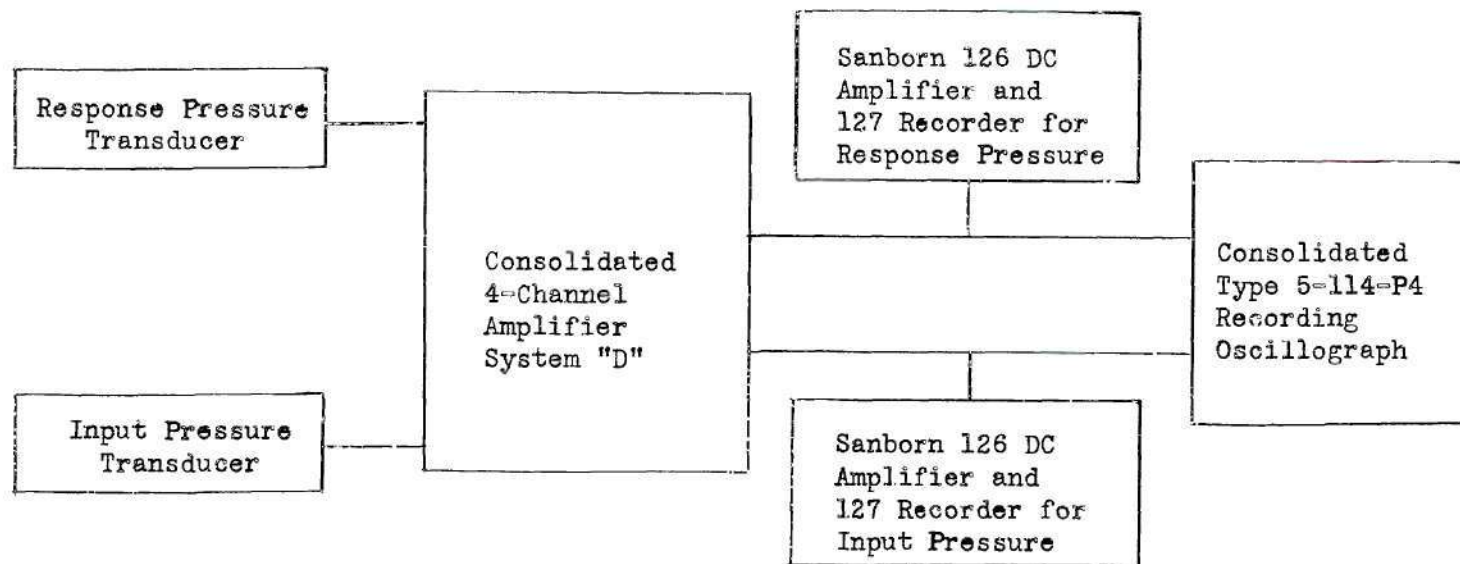


Fig. 11 Consolidated Instrumentation Circuit

was run at 10.8 inches per second. In addition two Sanborn Model 126 DC Amplifiers and Model 127 Recorders were in parallel with the two recording channels of the oscillograph to give immediate qualitative visual readings of each run.

CHAPTER III

PROCEDURE

The experiments were conducted outdoors in Research Area No. 2 of the Georgia Institute of Technology.

The test procedure consisted of putting the desired test configuration together, obtaining compressed air, testing the system for leaks, calibrating, bolting the nozzle and diaphragm to the shock tube, setting the instrumentation, firing, and reducing data.

Test configuration.--The desired test configuration of test line diameter and length, diameter reduction inserts, and receiver volume were connected. The correct Parker fitting plug, shown in Fig. 8, for the tube diameter was bolted to the pickup tube mounting plate. The bearing surfaces of the inserts were lightly covered with Mica Lubricant so the inserts could be removed easily. If the small volume was to be used, the upstream end plate with the Parker fitting for the corresponding tube diameter was bolted on. If either of the two larger volumes were to be used, the test line was joined to the appropriate fitting on the upstream end of the volume while the other fitting on that end was sealed with a blank cap. The response transducer was connected to the receiver volume.

Compressed air.--The four vapor separators on the compressor and the one on the control panel inlet line were drained. The storage tank was pumped up to 1300-1500 psig.

Leak tests.--The test line was connected to the fitting on the downstream

end of the volume and the entrance to the pickup tube was capped. If the response transducer was the 0-100 psig transducer the gate valve was closed to isolate it from the system. Pressure was applied to the test system in increasing amounts. At each pressure level the fittings were covered with a bubble soap film and the sensitive pressure gage observed to detect leaks. As the pressure was increased, the milliammeter to the response galvanometer was watched to detect a leak in the gate valve which isolates the 0-100 psig transducer. If any leaks were detected, pressure was bled from the system; the leaking fitting was tightened; and the procedure was repeated until the system would hold 1000 psig without leaking.

Calibration.--A calibration was made for each transducer for each amplifier attenuation setting. Stabilized pressure readings of the sensitive gage were recorded for five or six ascending pressures and five or six descending pressures to completely cover the pressure range of each amplifier attenuation as shown in Table 3. Simultaneously a pressure trace was recorded on the oscillograph. The displacement of the transducer trace was measured in fiftieths of an inch. The calibration pressure was plotted against the trace displacement for each transducer and each attenuation setting. The calibration plots were linear. Several complete calibrations were made during the period of tests. Spot calibrations were made daily and consisted of 5-7 stabilized pressure readings for each attenuation. These daily checks were over-plotted on the original calibrations to determine if the slope of calibration line changed. The maximum slope variation of the pressure input transducer was 2.4 per cent, while four of the seven attenuations did not measurable change. None of the slopes of the 0-100 psig response transducer measurable changed. The maximum variation of slope for the 0-1000 psig response transducer was 1.7 per cent.

Table 3. Amplifier Attenuation Settings
and Pressure Ranges

Hieland 119 Amplifier:

<u>Shock Tube Pressure (psig)</u>	<u>Input Amplifier Attenuation Setting</u>	<u>Pressure Range (psig)</u>
50	1.0	0-50
100	0.5	0-100
200	0.2	0-200
350	0.1	0-500
500	0.1	0-500
700	0.05	0-1000
1000	0.05	0-1000

C. E. C. 1-113 B Amplifier:

<u>Shock Tube Pressure (psig)</u>	<u>Input Amplifier Attenuation Setting</u>	<u>Pressure Range (psig)</u>	
		<u>0-1000 psig Transducer</u>	<u>0-100 psig Transducer</u>
50	1	0-80	0-10
100	1.5	0-120	0-15
	2	0-160	0-20
200	3	0-240	0-30
350	5	0-400	0-50
500	7	0-560	0-70
700	10	0-800	0-100
1000	15	0-1000	

Calibrations were necessarily slow because of the long stabilization period required for each pressure reading. This could be improved by putting a bypass tube with a needle valve around the orifice in the air line of the sensitive pressure gage. The valve could be opened for calibrations, thus saving considerable time in calibration, and closed to operate, thus protecting the gage in event of a premature rupture of the diaphragm. While calibrating the 0-1000 psig transducer the valve to the 0-100 psig transducer was closed.

Nozzle and diaphragm.--After the leak test and spot calibration, the cap was removed from the entrance of the pickup tube; the air line to the receiver volume was disconnected and the fitting capped off. The valve to the 0-100 psig transducer was opened and the pressure transducers positioned normal to the test line. The diaphragm for a 1000 psig shock tube pressure was put into position on the nozzle flange, as shown in Fig. 4, and the nickel chrome wire was inserted between the two downstream film layers. A strip of insulating tape was put under and over the two flattened lead-in wires of the heating element and the diaphragm then taped in position. The nozzle, diaphragm and heating wire assembly were bolted onto the shock tube. As the bolts were tightened the ohmmeter was used to test for a short circuit. After the nozzle was bolted in place the position of the pickup tube with respect to the nozzle was checked to be centered laterally and vertically and $1/8$ in. upstream (inside) from the nozzle lip. The position was corrected, if need be, by positioning the shock tube table. The transformer leads were connected to the heating element leads and the ohmmeter checked for a circuit. The area downstream of the shock tube was inspected for tools or debris and cleared.

Instrumentation.--The attenuation of the amplifier for the input pressure

transducer was set according to Table 3. The attenuation of the response transducer that would give nearly full scale deflection for the expected response was estimated from previous runs or found from a conservative trial run. The zero trace positions were adjusted and the Sanborn recorders were checked for trace position, sensitivity, and stylus temperature.

Firing.--Approximately 30 seconds prior to firing, while pressurizing the shock tube, a whistle was blown to warn people in the vicinity of the impending blast. After the shock tube pressure was stabilized and recorded the valve to the shock tube was closed. The Sanborn recorders and oscillograph were started and the switch controlling current to the heating wire was closed. The diaphragm ruptured emitting a shock wave from the tube. After the run, the oscillograph record number was noted and the Sanborn tracers were evaluated to determine if the results appeared reasonable. If they were, the diaphragm was changed and the run procedure repeated for the next shock tube pressure. A series of seven runs of 1000, 700, 500, 350, 200, 100, and 50 psig shock tube pressures could be completed with the 1300 psig reservoir air. The diaphragm thickness for each shock tube pressure is given in Table 1.

Data reduction.--After a series of runs the oscillograph film was developed. The data was reduced by finding the maximum deflection from the zero position for each trace to the fiftieth of an inch. This deflection was multiplied by the slope of the calibration curve for the appropriate transducer and amplifier attenuation to obtain $P_{I_{max}}$ and $P_{R_{max}}$.

CHAPTER IV

RESULTS

The results of the investigation, plots of $P_{I_{\max}}$ versus $P_{R_{\max}}$ for different receiver volumes and for each of the eight configurations tested are shown in Figs. 12 through 19 in the Appendix. The configurations are listed in Table 4.

The data for the 10.55 cu. in. volume was taken from Kilburg³ with check runs made of his data overplotted. The check runs on his data were with the Visicorder equipment which had a higher frequency response of 900 cps as recommended by his report. The agreement with his data was good. Kilburg made runs at shock tube pressures of 50, 100, 200, 500, 700, and 1000 psig. He reported that linear relationships seemed to exist between $P_{R_{\max}}$ and $P_{I_{\max}}$ in two regimes: 0-300 psig $P_{I_{\max}}$ and 300-900 psig $P_{I_{\max}}$. As a result, during this investigation runs were made at 350 psig (approximately 300 psig $P_{I_{\max}}$) as well as at the six shock tube pressures tested by Kilburg.

Straight lines were faired through the data points of $P_{R_{\max}}$ and $P_{I_{\max}}$ in order to derive a simple relation which would qualitatively predict the effect of variation of receiver volume on the pressure attenuation. As a rule the point corresponding to the 1000 psig run shows a lower $P_{R_{\max}}$ (more attenuation) than indicated by the straight lines, Figs. 12 through 19. Because of this runs should be conducted at shock tube pressures higher

³Kilburg, op. cit., pp. 14, 17.

than 1000 psig to determine if there is a trend of increasing attenuation as the $P_{I_{\max}}$ increases.

The slopes, K , of the straight lines through the test points plotted against volume for each configuration are shown in Fig. 20. On logarithmic graph paper these points were, essentially, parallel straight lines. Each line corresponded to a different test system configuration given in Table 4. The effect of variation of receiver volume can be written thusly:

$$P_{R_{\max}} = K P_{I_{\max}}$$

where

$$K = CV^{-0.64} \quad \text{from Fig. 20.}$$

Then

$$P_{R_{\max}} = CV^{-0.64} P_{I_{\max}}$$

where V is the receiver volume in cubic inches and C , a constant, is a function of tube length, tube diameter and fitting diameter. Since only two tube lengths, two tube diameters and two reduction fittings were tested, empirical values of C cannot be readily determined. Additional test runs should be made at intermediate configurations, that is, with tube lengths between one and fifteen feet, tube diameters between 0.242 and 0.370 inches, and fittings with diameter ratios between 0.50 and 1.00, in order to empirically determine C . From Fig. 20 it can be seen that C decreases as test tube length increases, as tube diameter decreases and as reduction fitting diameter decreases.

Included in Figs. 12-14, 16, and 18 are data points for repeat runs (flagged symbols) which show the degree of repeatability. Reference to

these figures indicates that the repeatability is qualitatively good. It is believed that the repeatability is due to the manner in which the diaphragms burst. Most of the time the heating element would cut a key-hole shaped flap which would lay along the periphery of the nozzle. This flap was not always the same size. On several occasions the diaphragm would "sunburst" resulting in a hole with scalloped edges. Another factor which might effect the repeatability of data is the variation in conditions (temperature, humidity, and density) of the shock tube air mass prior to firing. An investigation of these effects would be worthwhile in order to improve the repeatability and hence the accuracy of the data, although it is believed that this latter effect would be negligible.

For the parameters tested it was found that they were effective in attenuating shock waves in the following descending order:

1. increase in volume.
2. decrease in fitting diameter.
3. decrease in tube diameter.
4. increase in tube length.

CHAPTER V

CONCLUSIONS

Within the limitations of the system geometric configurations tested, as listed in Table 4, and range of shock tube pressures, it is concluded that:

1. The flat frequency response (500 cps) of the instrumentation is apparently adequate for pressure attenuation investigations as shown by the good agreement between Kilburg's (Reference 2) data and the spot checks conducted with instrumentation capable of a flat frequency response of 900 cps.

2. The parameters tested were effective in attenuating the shock wave in the following descending order:

- (a) increase in volume.
- (b) decrease in fitting diameter.
- (c) decrease in tube diameter.
- (d) increase in tube length.

3. The effect of variation of receiver volume on shock wave attenuation in a typical missile plumbing system can be given qualitatively by the following empirical equation:

$$P_{R_{\max}} = CV^{-0.64} P_{I_{\max}}$$

where C is a function of line diameter, line length and reduction fitting diameter.

4. Additional test runs should be made:

(a) of intermediate configurations to determine C empirically.

(b) to investigate the effect of the method of diaphragm rupture on repeatability of data.

(c) to investigate the effect of temperature, density, and humidity of the shock tube air mass on repeatability of data.

(d) at higher shock tube pressures to determine if there is more than a linear trend toward greater attenuation at higher maximum input pressures.

CHAPTER VI

RECOMMENDATIONS

It is recommended that:

1. A bypass line, with needle valve, around the sensitive pressure gage orifice be installed to reduce calibration time during further testing.
2. Additional test runs be made:
 - (a) of intermediate configurations to determine C empirically.
 - (b) to investigate the effect of the method of diaphragm rupture on repeatability of data.
 - (c) to investigate the effect of temperature, density, and humidity of the shock tube air mass on repeatability of data.
 - (d) at higher shock tube pressures to determine if there is more than a linear trend toward greater attenuation at higher maximum input pressures.
3. A theoretical investigation be made of this problem.

APPENDIX

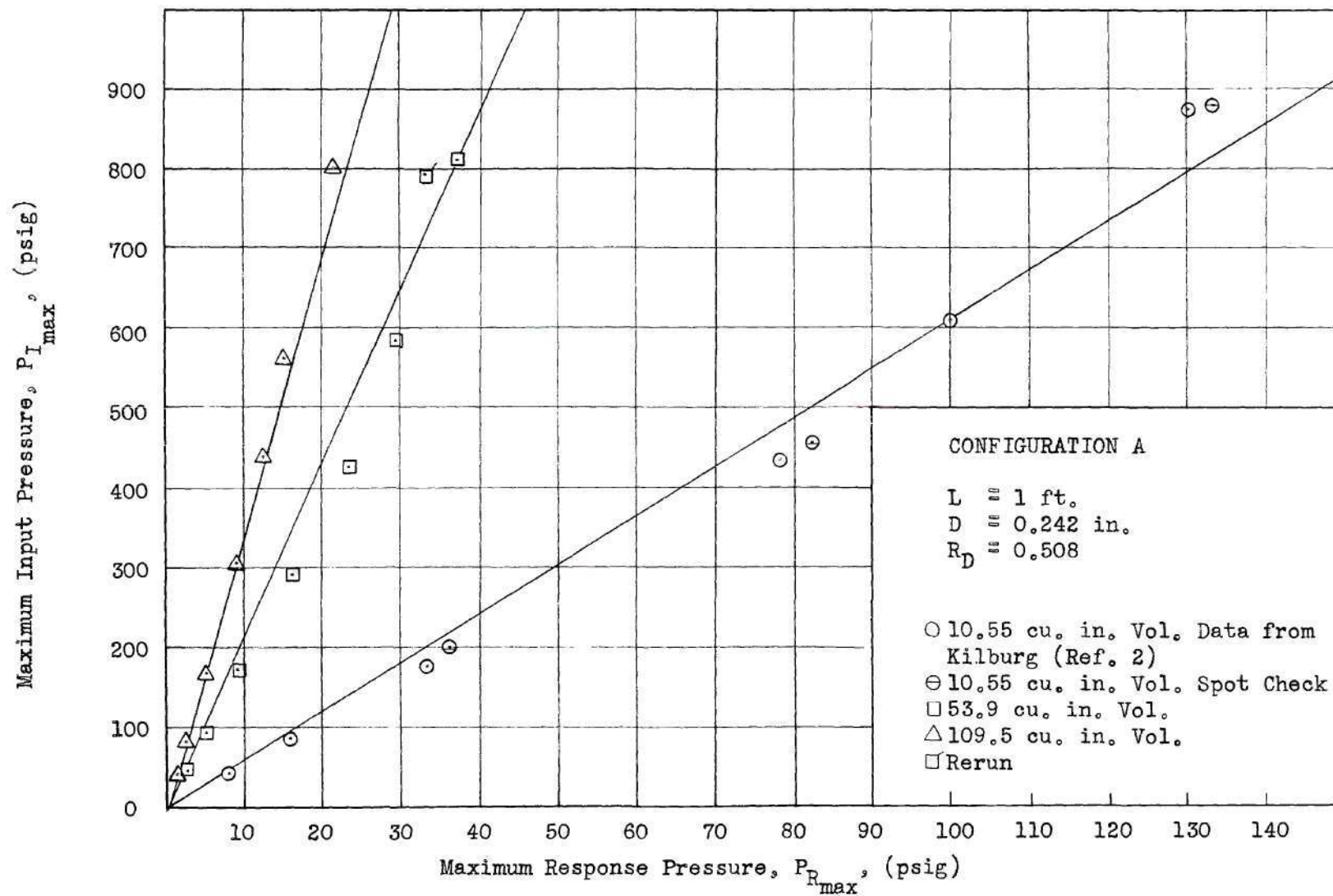


Fig. 12 Pressure Attenuation for Configuration A

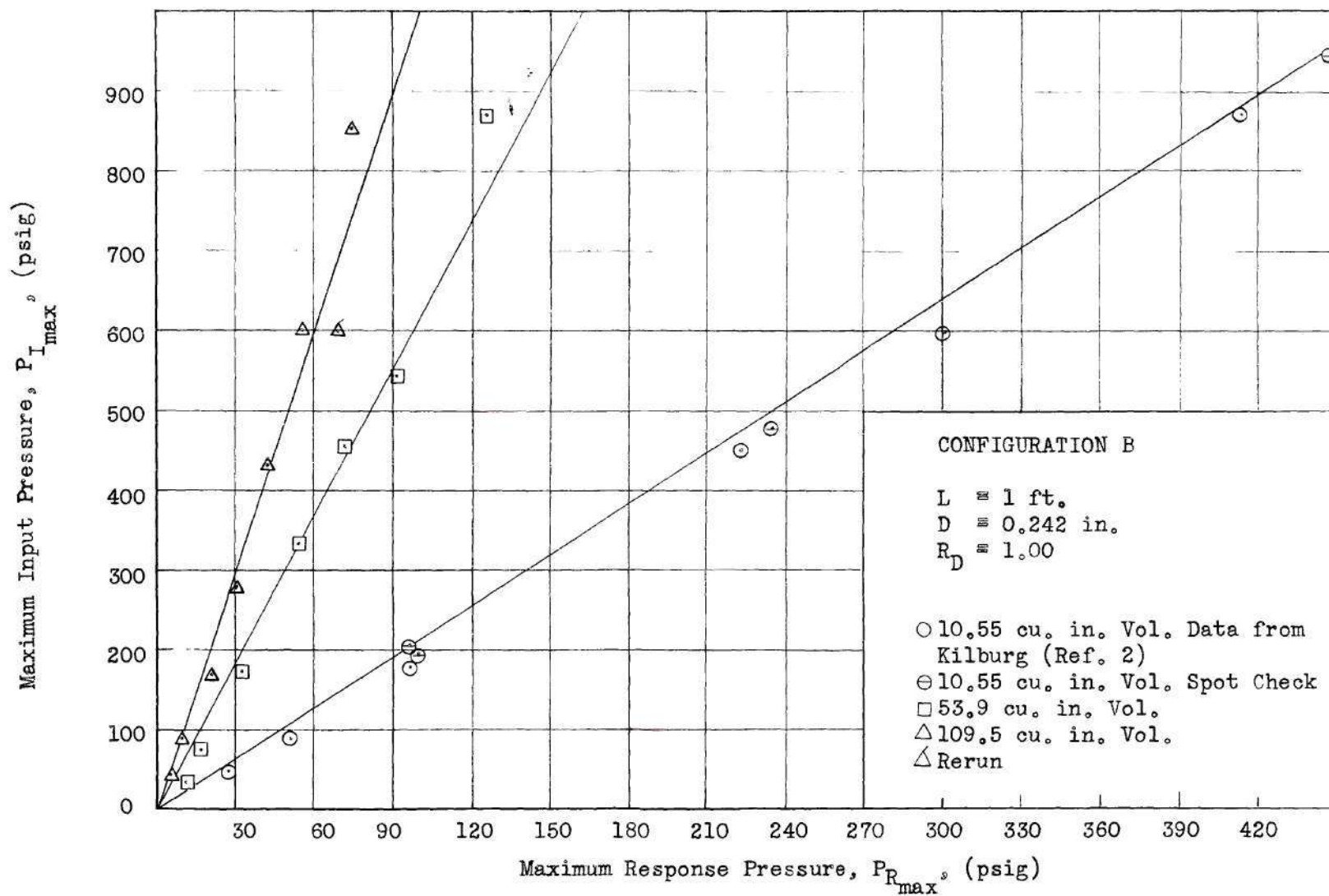


Fig. 13 Pressure Attenuation for Configuration B

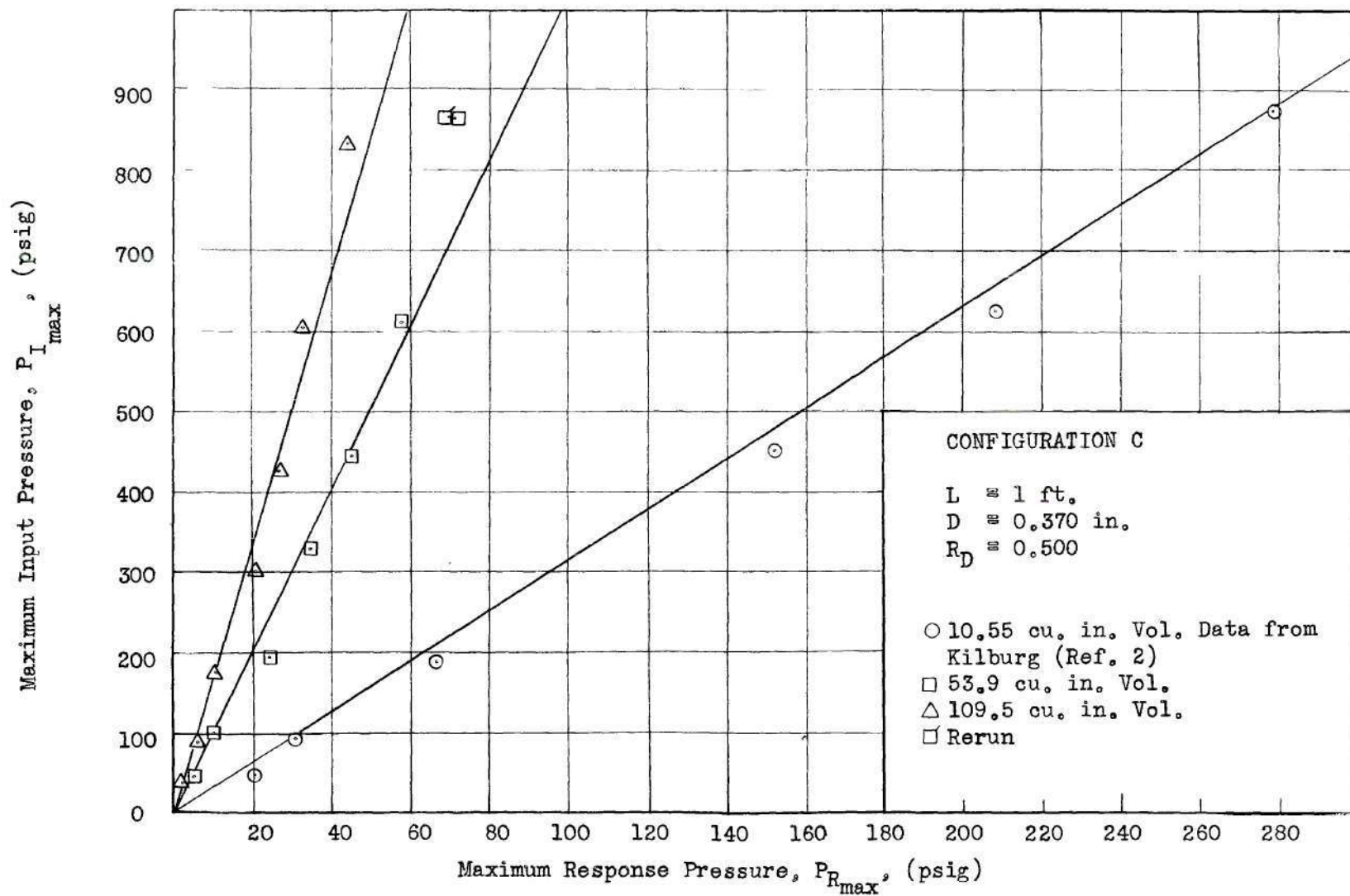


Fig. 14 Pressure Attenuation for Configuration C

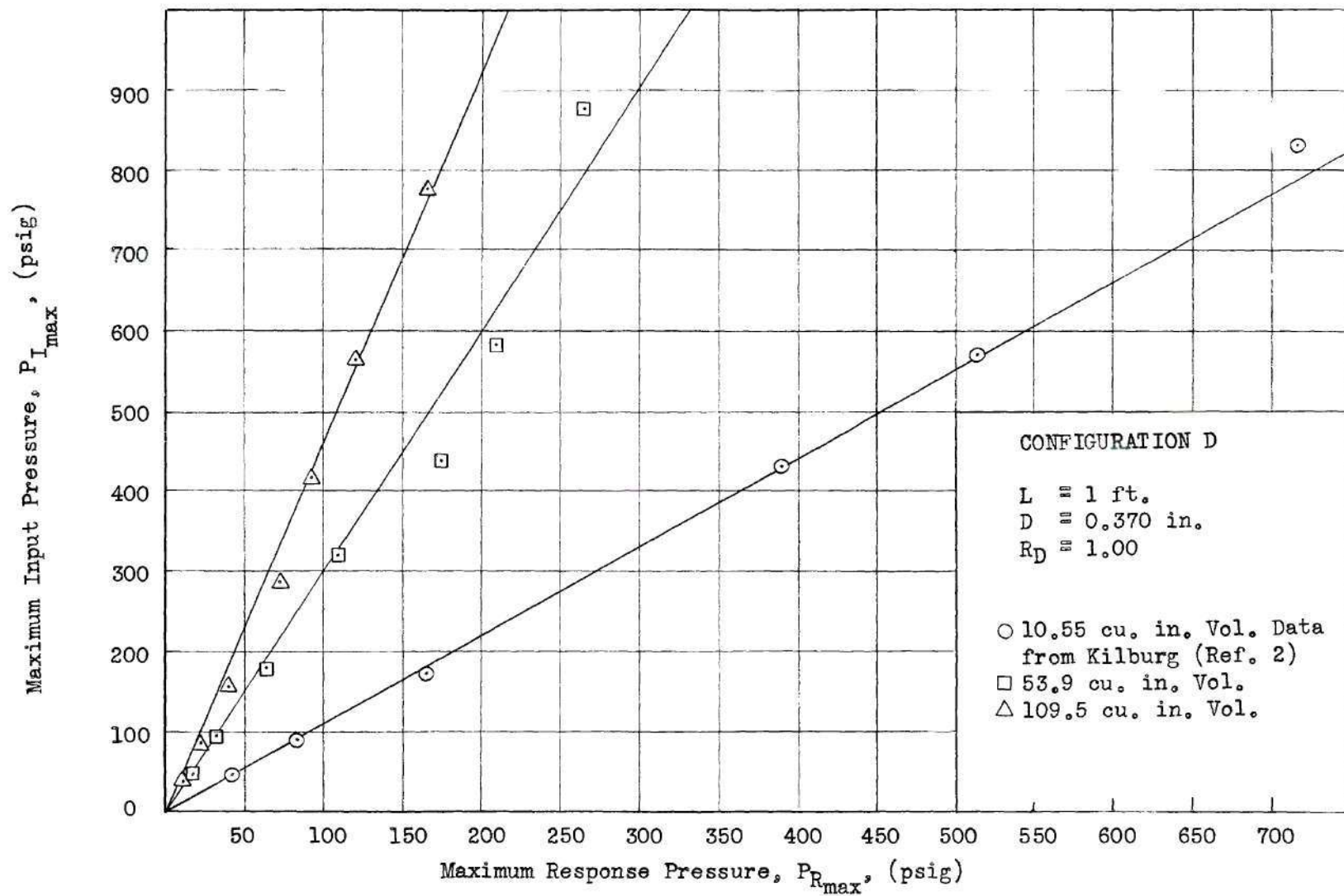


Fig. 15 Pressure Attenuation for Configuration D

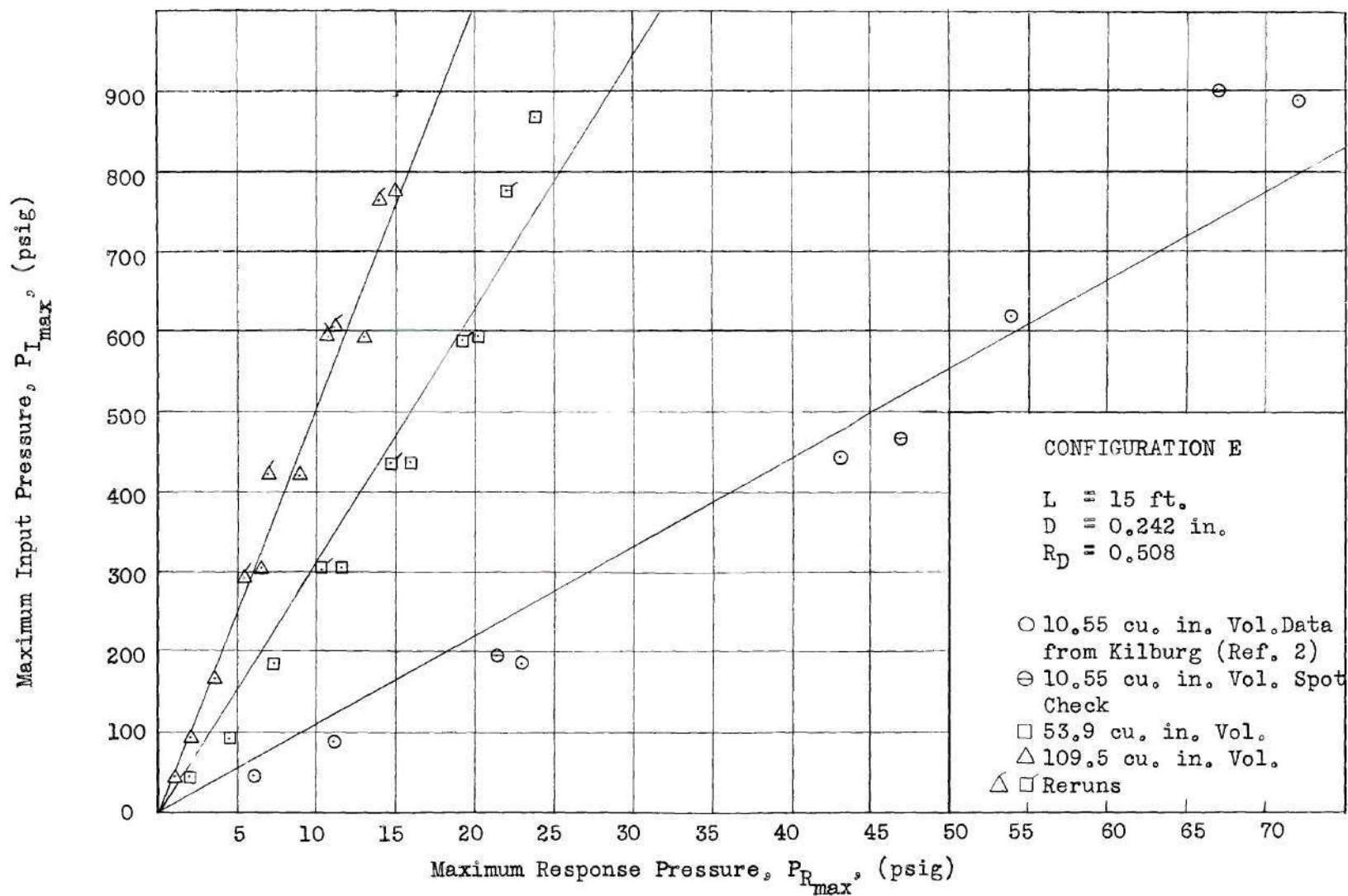


Fig. 16 Pressure Attenuation for Configuration E

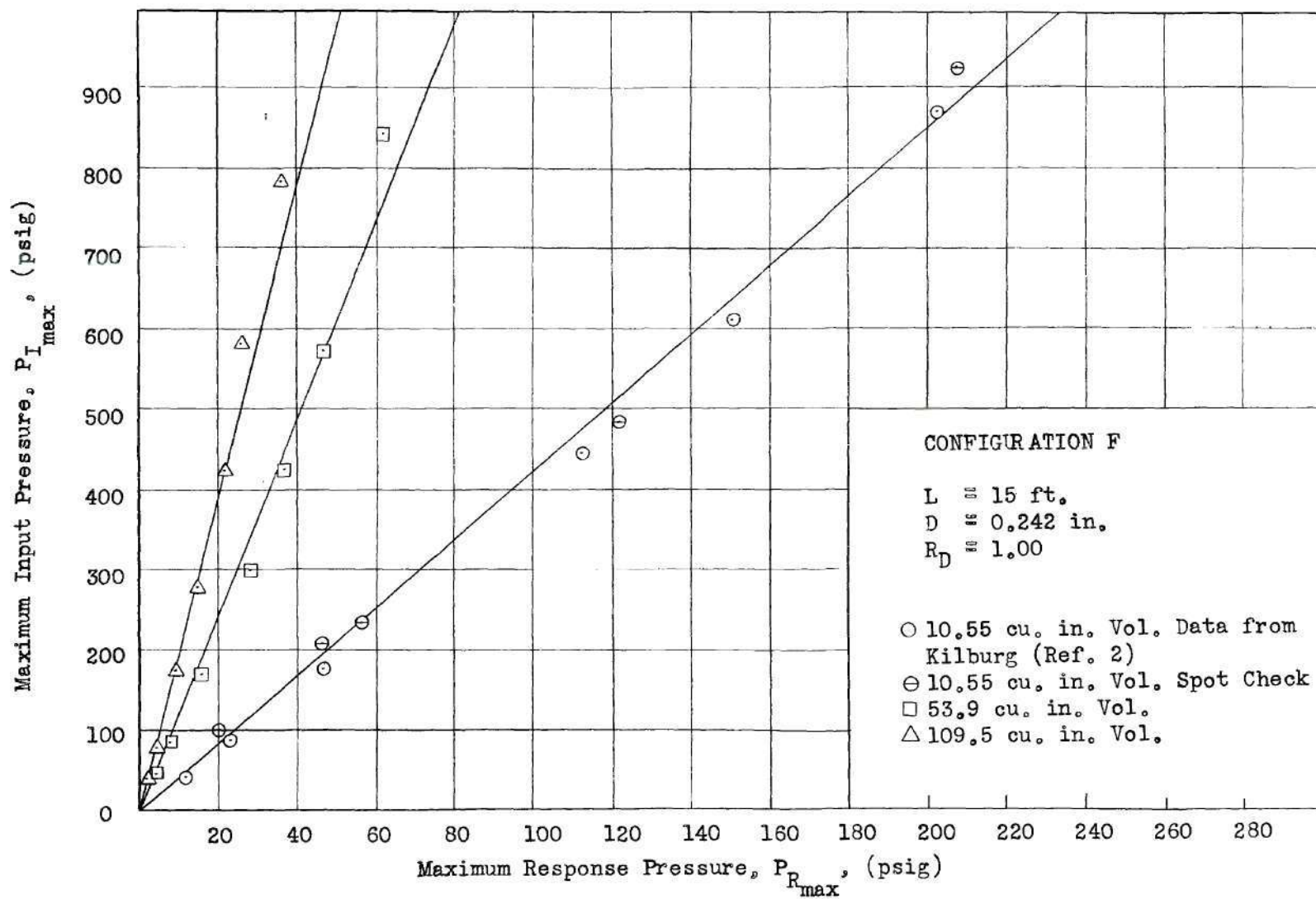


Fig. 17 Pressure Attenuation for Configuration F

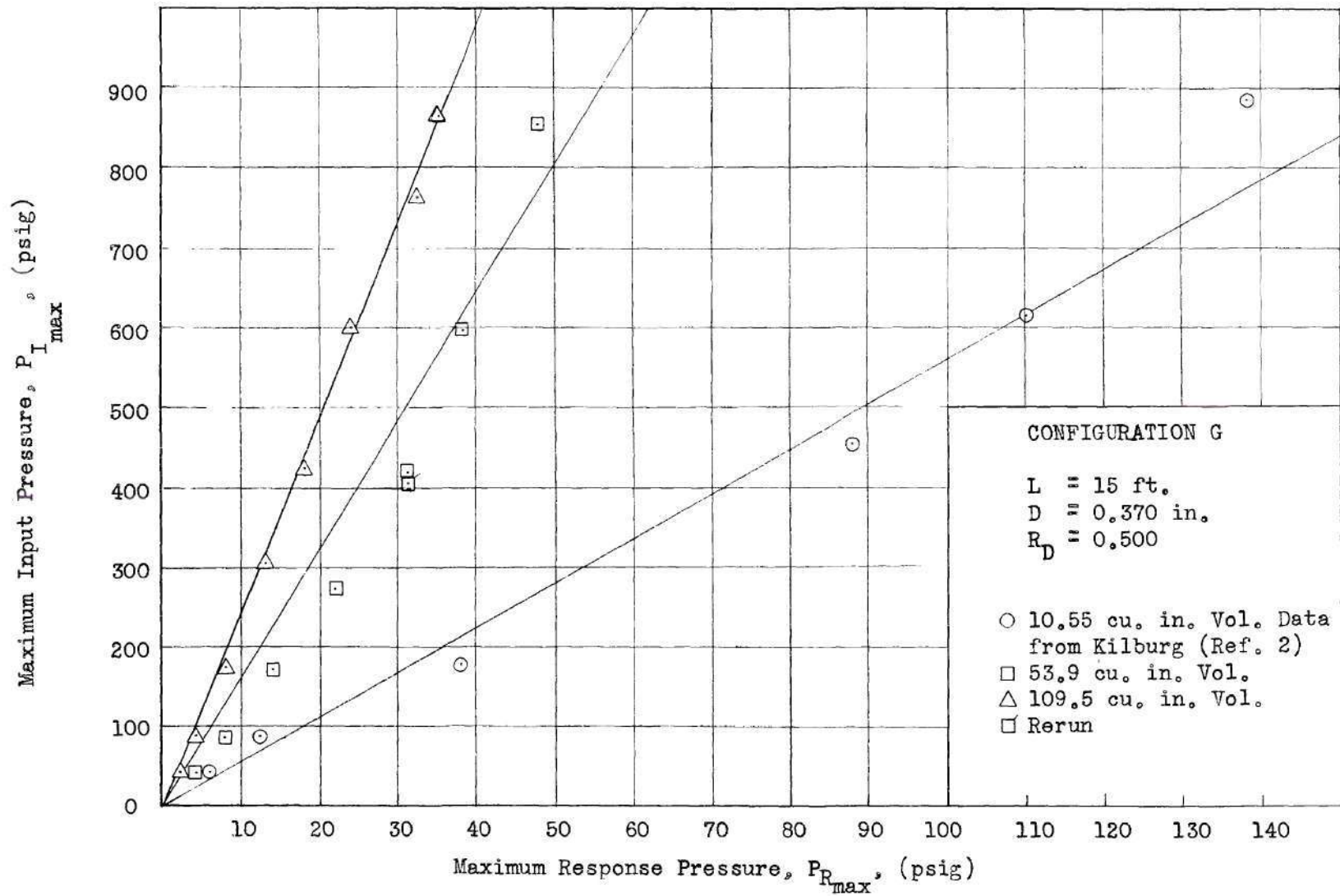


Fig. 18 Pressure Attenuation for Configuration G

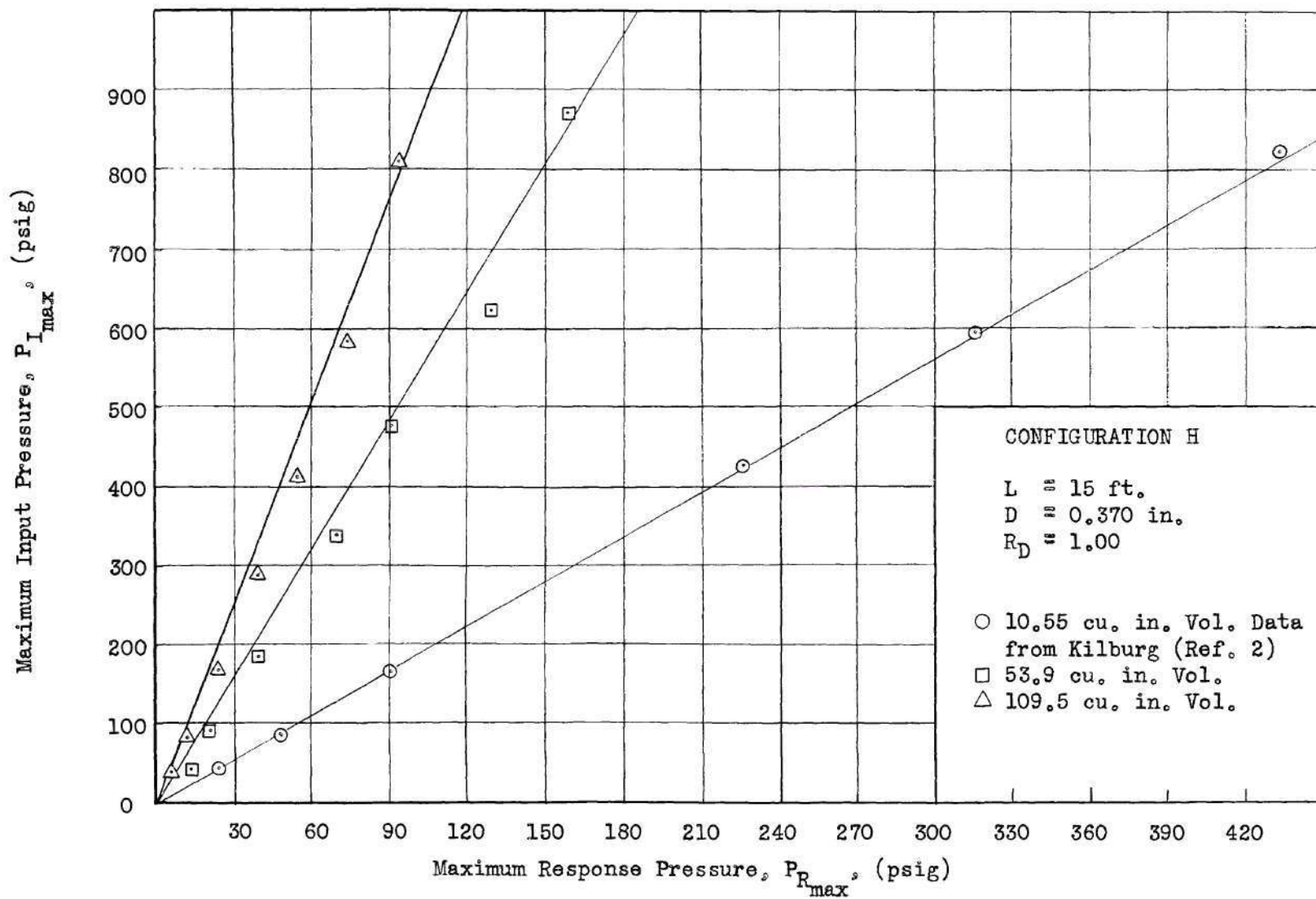


Fig. 19 Pressure Attenuation for Configuration H

Table 4. Configurations

<u>Configuration:</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>	<u>F</u>	<u>G</u>	<u>H</u>
Tube length, L, ft.:	1	1	1	1	15	15	15	15
Tube diameter, D, in.:	.242	.242	.370	.370	.242	.242	.370	.370
Reduction fitting, R_D :	.508	1.00	.500	1.00	.508	1.00	.500	1.00

Each of the above configurations was tested with each of the three receiver volumes (10.55, 53.9, and 109.5 cu. in.) and over the range of shock tube pressures.

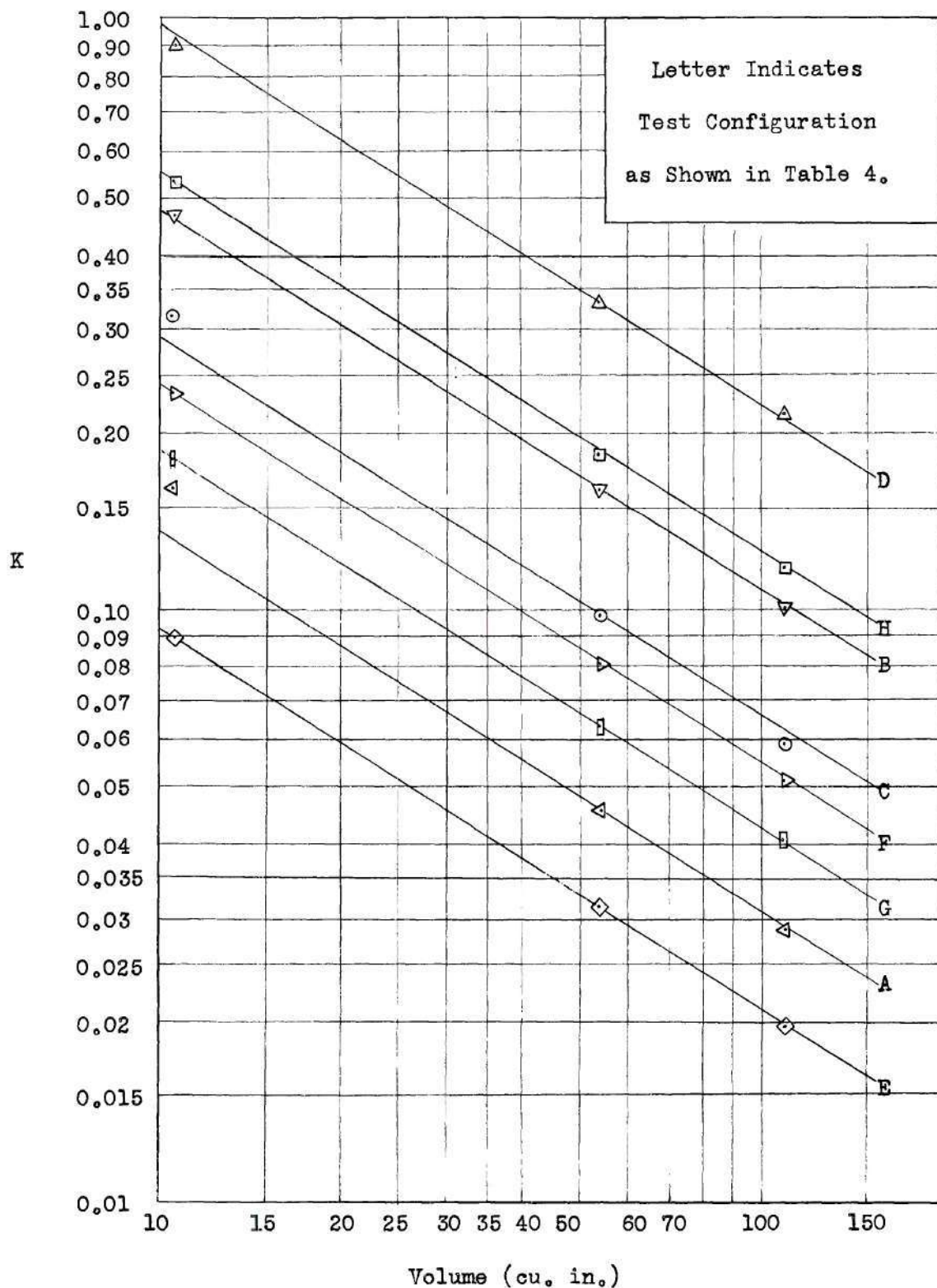


Fig. 20 Empirical Constant, K , vs Receiver Volumes
for Test Configurations

REFERENCES

1. DeJarnette, F. R., An Experimental Investigation of Pressure Attenuation in Typical Missile Plumbing Systems Subjected to Shock Wave Inputs--Part I, Unpublished Master's Thesis, Georgia Institute of Technology, 1958.
2. Kilburg, R. F., An Experimental Investigation of Pressure Attenuation in Typical Missile Plumbing Systems Subjected to Shock Wave Inputs--Part II, Unpublished Master's Thesis, Georgia Institute of Technology, 1958.